HARMO 19

Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
3-6 June 2019, Bruges, Belgium

Modelling pedestrian exposure in an urban hot-spot combining results from a computational fluid dynamic model and pedestrian microsimulations

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Introduction

- Air pollution → largest environmental health risk in Europe (EEA, 2017)
- High percentage of population lives in cities (e.g. > 70% in Europe)
- Reduced ventilation and traffic emissions in urban environments → High pollution in cities (NO_2, PM_{10},…). **Urban hot spots**

Population are exposed to pollutant concentrations exceeding the EU AQ standards

Impact on human health (≈ 400 000 premature deaths in EU-28 in 2013)

How can urban air pollution be mitigated?

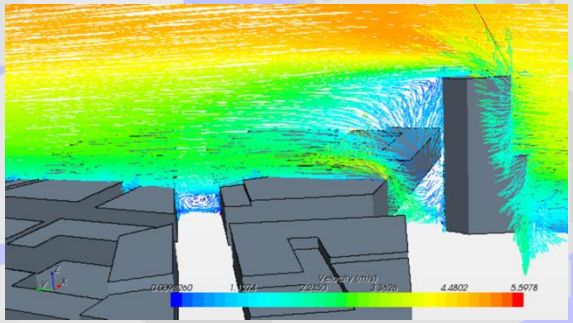
How can population exposure be reduced?

HOW CAN POPULATION EXPOSURE BE ESTIMATED

Introduction

- Atmosphere – Urban Surfaces Interactions → Complex flow circulation in city
- Reduced Ventilation in Streets
- Complex temporal and spatial variability of traffic emission

High pollutant concentration and **strong gradient of concentration** (spatial and temporal)



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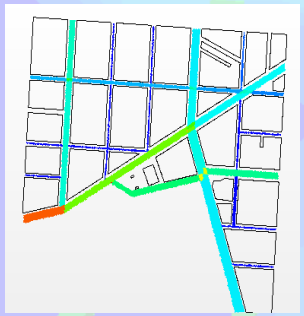
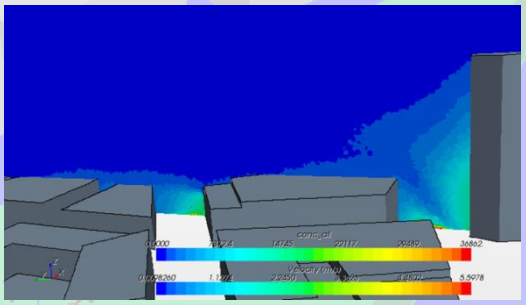
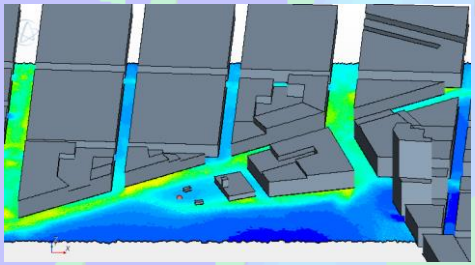




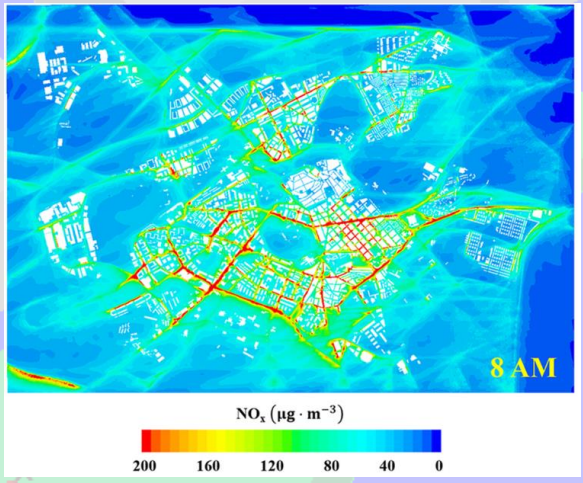


Street Scale

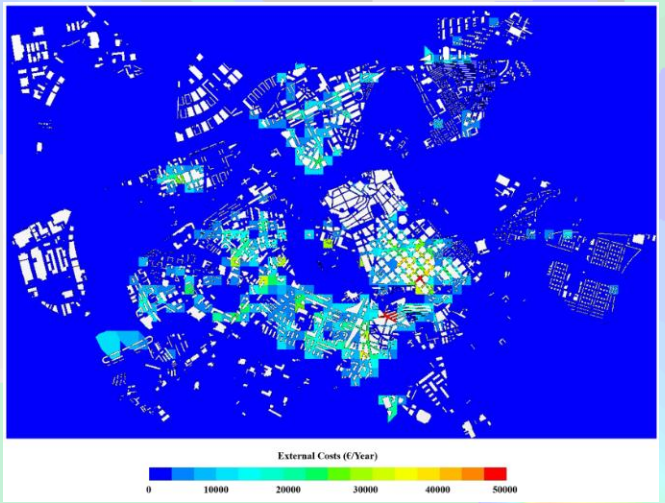
High Spatial Resolution Needed

Introduction

- **How to compute population exposure?**
- Computation of Population Exposure (Health Impact) to Urban Air Pollution:
  - **Air Quality Monitoring Station** + **Population Data** (resolution of order of few Km^2)
  - **Mesoscale Model** (resolution of order of few Km^2) + **Population Data** (resolution of order of few Km^2)
  - **Mesoscale Model** (resolution of order of few Km^2) + **Population dynamics based on mobile phone data** (*Picornell et al., 2018*)
  - **CFD Model** (resolution of order of few m^2) + **Population Data** (resolution of order of 100 m x 100 m)



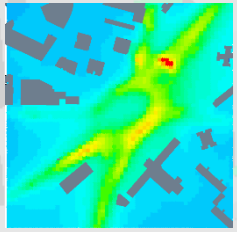
(Rivas et al., 2019)



Main Objective and Methodology

- **Main Objective**: **Quantify the exposure of pedestrians to NO_x in a real urban hot-spot considering high resolution concentration maps and the pedestrian flows throughout the study area**

- **High resolution concentration maps → CFD modelling**



(µg m^{-3})

Hourly maps during an average day

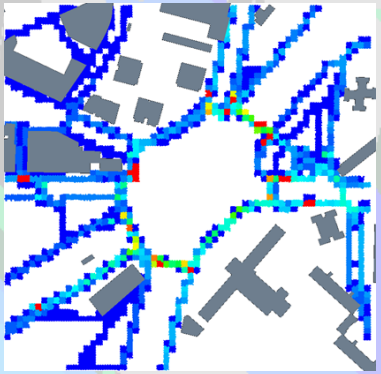
- **Pedestrian data → Pedestrian flow microsimulations**

(person·s)

Pedestrian flows throughout the study area for different hourly scenarios

Total Exposure

(person·s µg m^{-3})

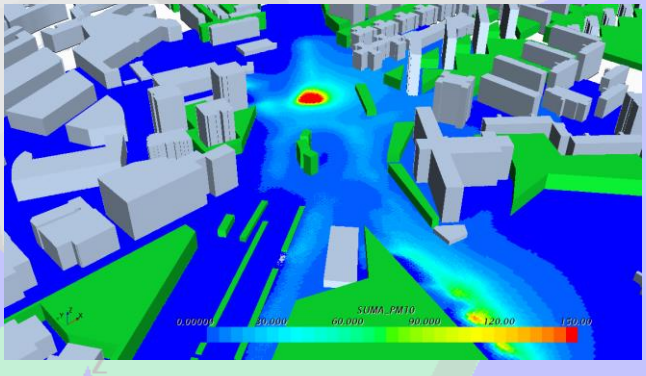


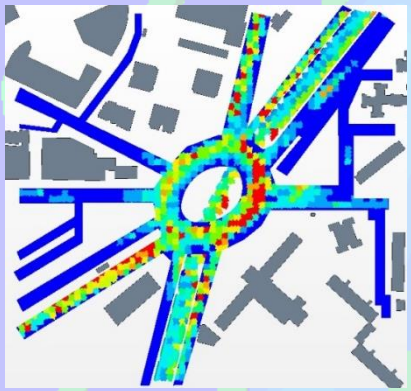
- **Meaning of Total Exposure in this study: Air Pollution breathed by all pedestrians** who are in the study area (µg·m^{-3}·person·s)

- For example, a value of 100 µg·m^{-3}·person·s could be due to 1 person who stay 100s or to 100 people who stay 1s.

Study Area

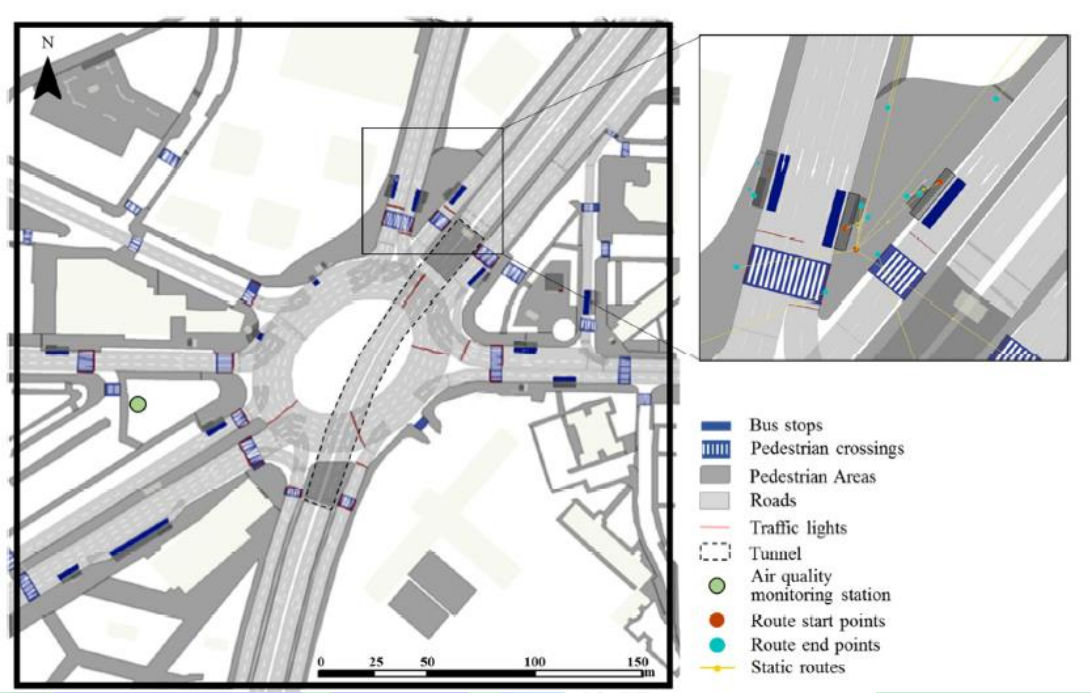
- Highly polluted zone in southern Madrid (Spain). Complex area: heavily trafficked roundabout, tunnel, vegetation, …
- TECNAIRE PROJECT
- Domain size: 300m x 300m
- Air quality monitoring station (●). City Council network
- Passive samplers at 3 m height (period-averaged concentration of NO_2)
- Period: 9th – 27th February 2015.





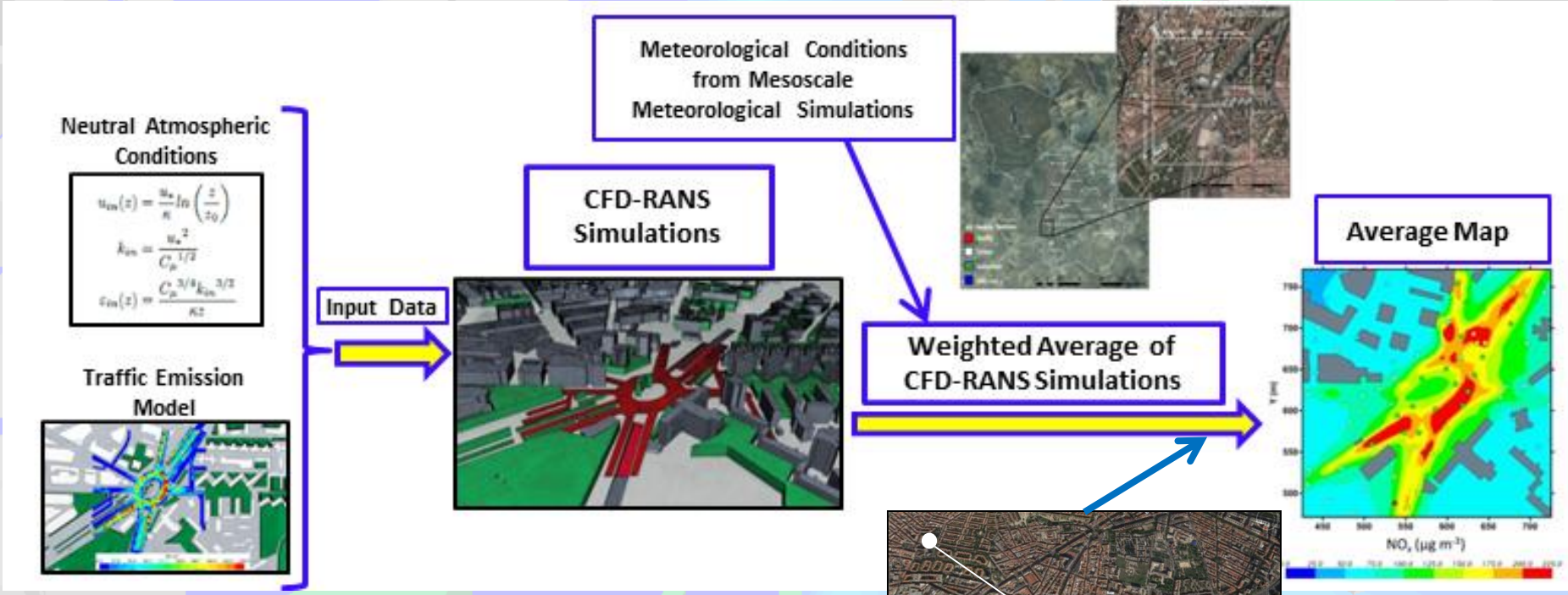
Pedestrian Microsimulations

- Traffic and pedestrian fluxes simulated with microscale modelling system VISSIM-VISWALK.
- Every posible route defined as a Pedestrian Static Route Decision using collected data (experimental campaign) as input or output of the areas from the simulation.
- Each individual pedestrian movement computed with 2 s resolution. Pedestrian locations interpolated to a 5m x 5m grid resolution and integrated troughout 1 hour for each scenario.
- 15 scenarios to simulate hourly evolution of a representative week considering weekdays and weekend days.



Concentration Modelling: Methodology

- **Methodology based on weighted average CFD-RANS simulations (WA CFD-RANS) (*Sanchez et al., 2017; Santiago et al., 2017*)**



Assumptions:

a) Non-reactive compounds → ~~Chemical Effects~~

b) Thermal effects are negligible

c) Concentration is inversely proportional to the wind speed

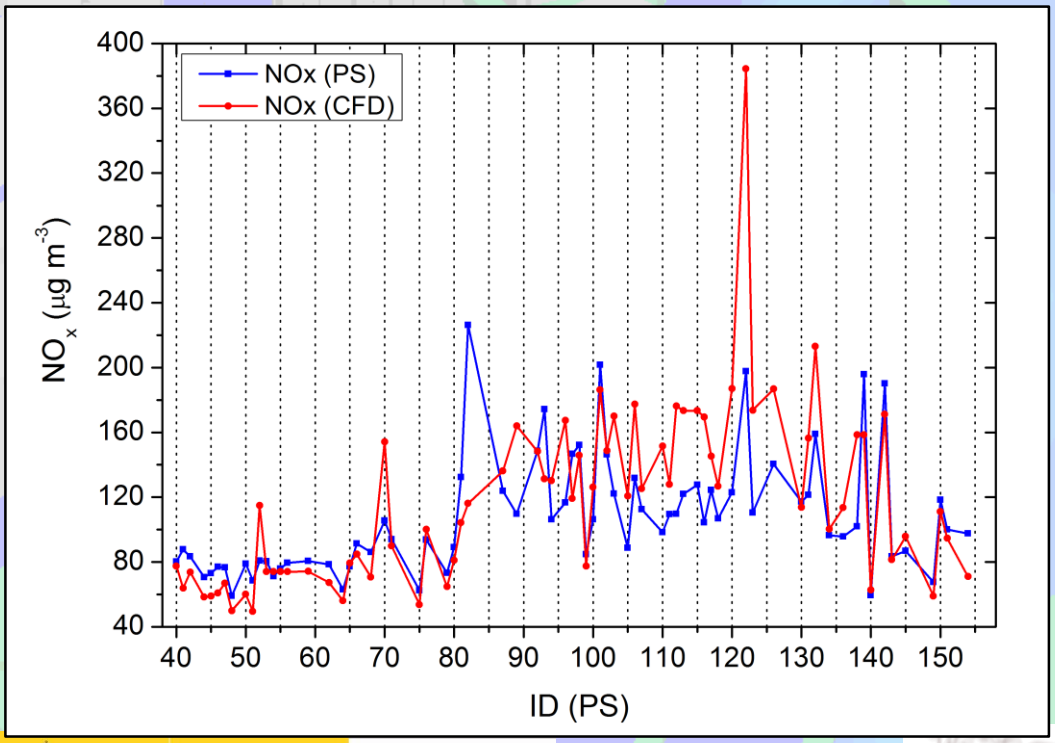
Background concentration from Urban Background Station (Farolillo)

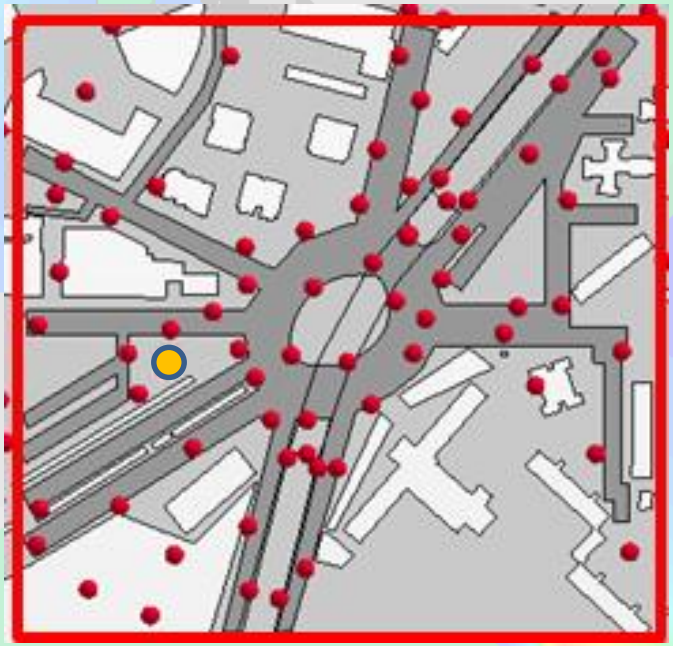
Concentration Modelling: Evaluation

- Zoom 300 m x 300 m → **72 passive samplers**
- Passive samplers: NO_2 averaged concentration over 444 h at 3 m. NO_2 is transformed into NO_x using the time average of the ratio at AQ station

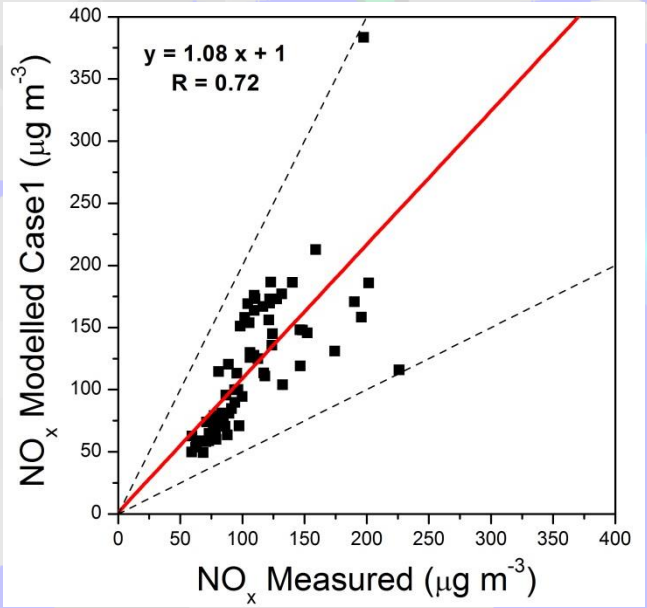
$$[NO_x] = \left(\frac{[NO_x]}{[NO_2]}\right)_{AQ\ Station} [NO_2]$$

- **NO_x averaged concentration over 444 h** is modelled.



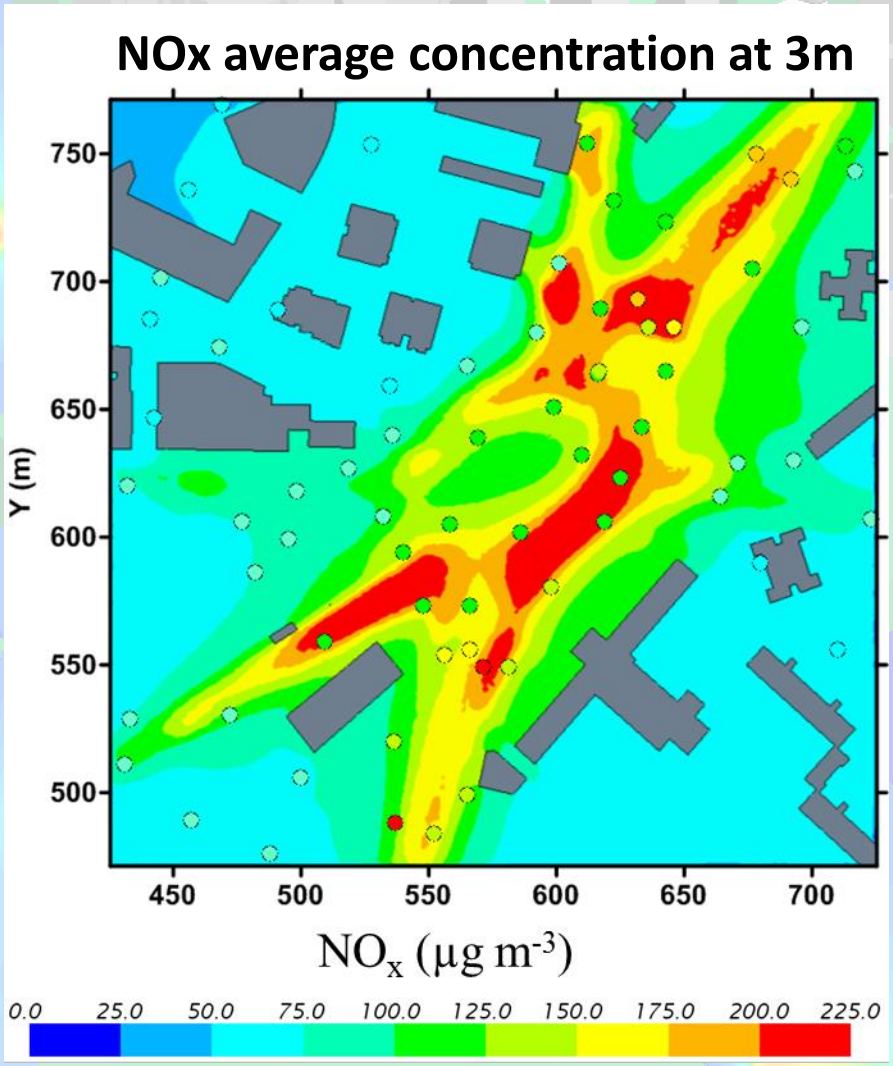


Concentration Modelling: Evaluation



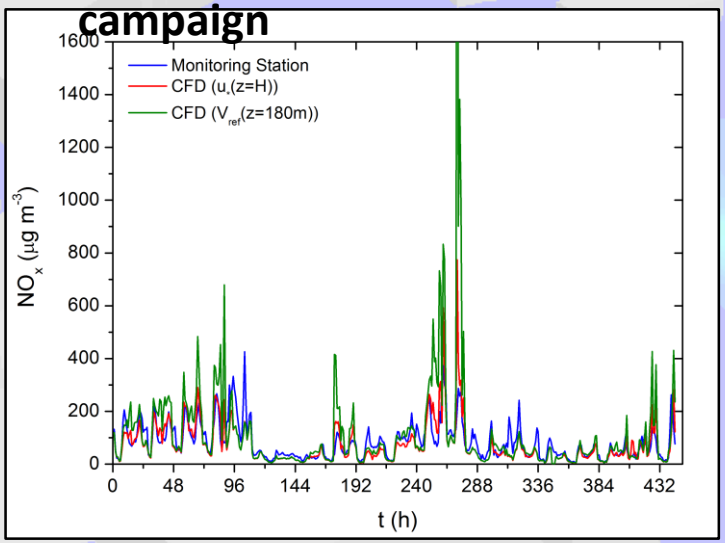
- Slight overestimation

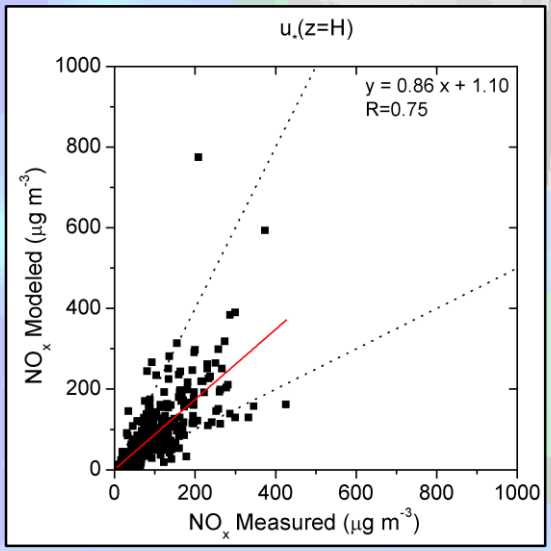
	$C_{mod}[u_*]$	Acceptance Criteria (Goricsan et al., 2011 and Chang et al., 2005)	
NMSE	0.11	<1.5	Good
FB	-0.09	-0.3 <0 <0.3	Good
R	0.72	0.5<R<0.8	Fair



Concentration Modelling: Evaluation

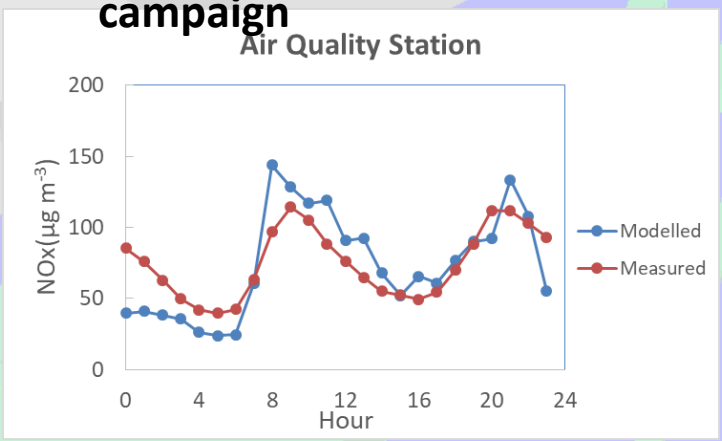
- Time evolution of concentration at AQ monitoring station during experimental campaign





	$C_{mod}\,[u_*]$	Acceptance Criteria (Goricsan et al., 2011 and Chang et al., 2005)	
NMSE	0.28	<1.5	Good
FB	-0.13	[-0.3,0.3]	Good
R	0.75	0.5<R<0.8	Fair

- Concentration at AQ monitoring station of an average day during experimental campaign



- NOx averaged during an average day:

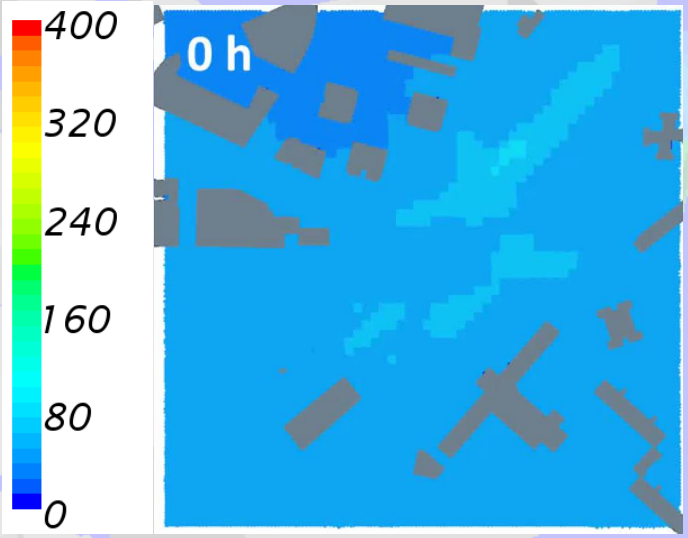
NOx Modelled = 74,2 µg m^{-3}

NOx Measured = 74.8 µg m^{-3}

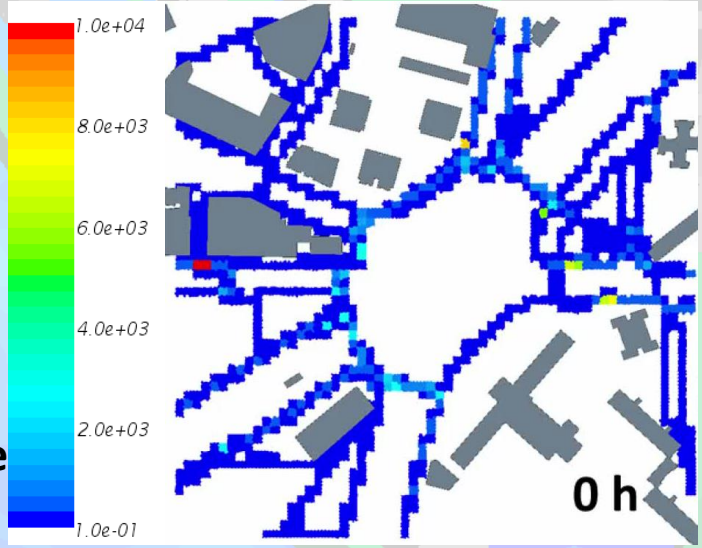
Results: Exposure Computation

- **Hourly Exposure during a Representative Average Day**

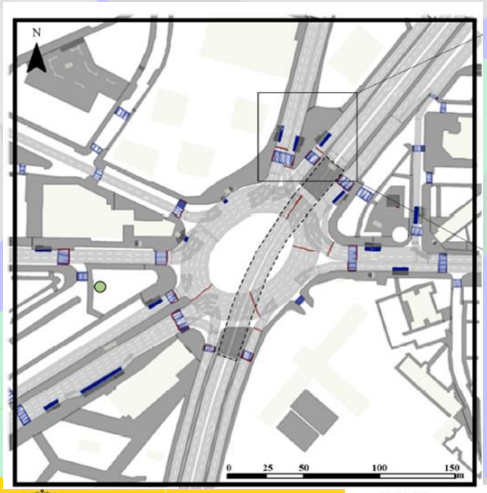
Hourly NOx (µg m^{-3})

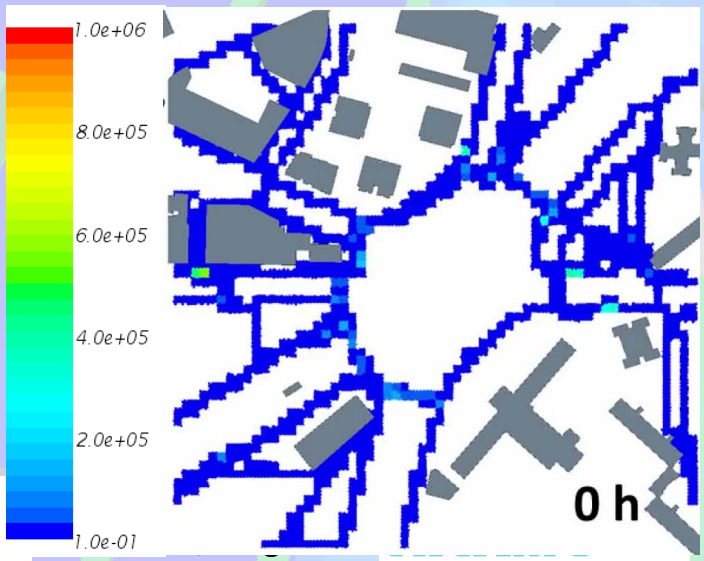


Pedestrians (person·s)



Total Hourly Exposure (person·s µg m^{-3})



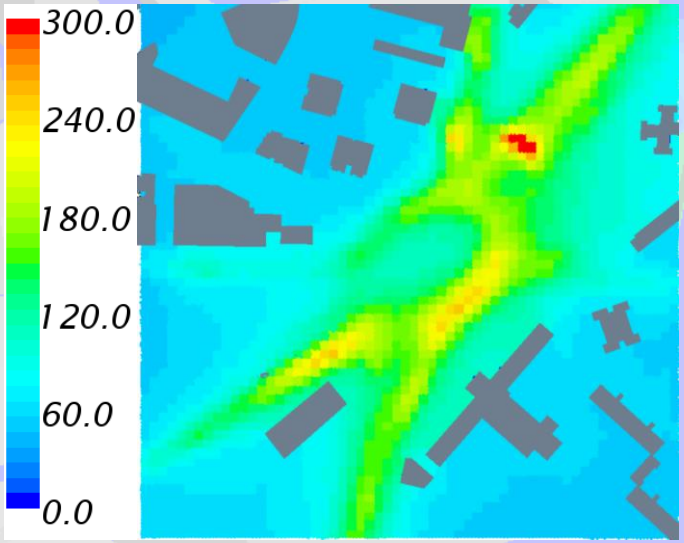


- Pedestrian position (bus stops) have an important influence on total daily exposure

Results: Exposure Computation

Daily Total Exposure

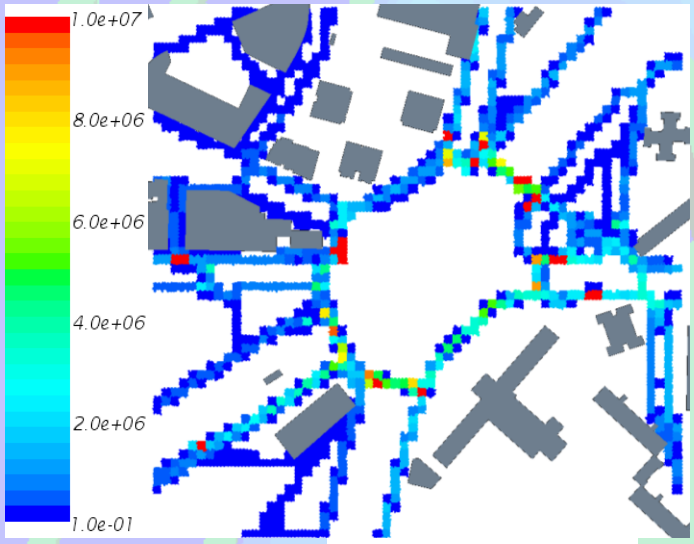
Daily Averaged NOx (µg m^{-3})



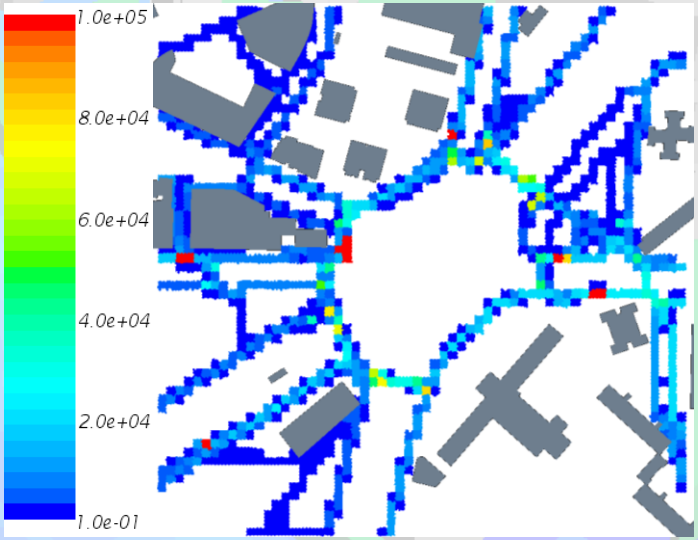
Daily Total Exposure (whole area) = 1.19E+09 person·s µg m^{-3}

13773 person·day µg m^{-3}

Daily Total Exposure (person·s µg m^{-3})



Daily Total Pedestrians (person·s)



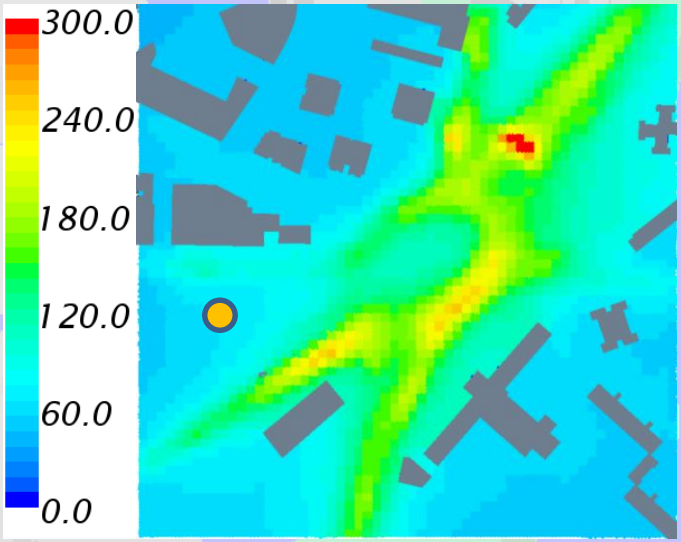
Daily Total Exposure computed aggregating individual grid cell exposure for every hour during the whole representative day

- Pedestrian position (bus stops) have an important influence on total daily exposure

Results: Exposure Computation

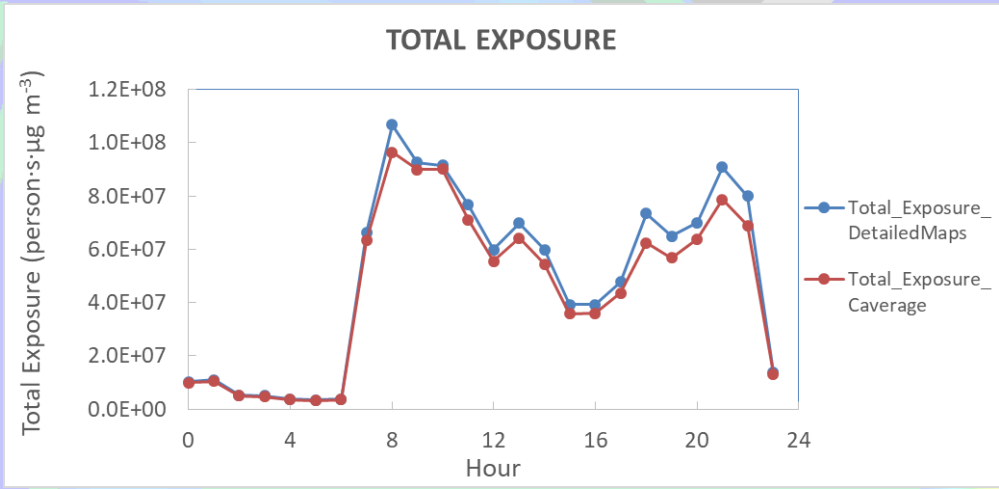
- **Daily Total Exposure** computed using **Spatial Average Concentration** (similar to mesoscale) and **Total Number of Pedestrians**

Daily averaged NOx (µg m^{-3})



NOx (average) = 95.1 µg m^{-3}

DAILY TOTAL EXPOSURE (person·s µg m^{-3})		Diferences
Detailed Maps	*1.19E+09*	*reference*
$C_{Average}(day) \cdot TotPed(day)$	0.91E+09	-23.1 %
$\sum_h (C_{Average}(h) \cdot TotPed(h))$	1.08E+09	-8.5 %

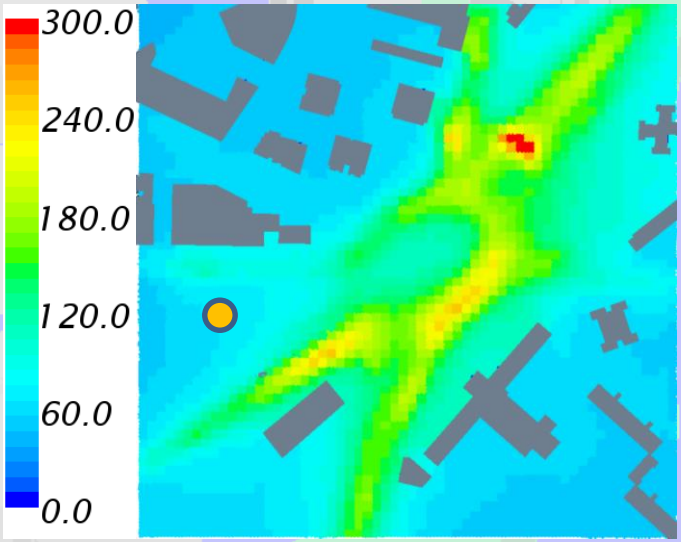


- Detailed maps can allow to design local strategies to decrease exposure at certain locations (e.g. bus stops)

Results: Exposure Computation

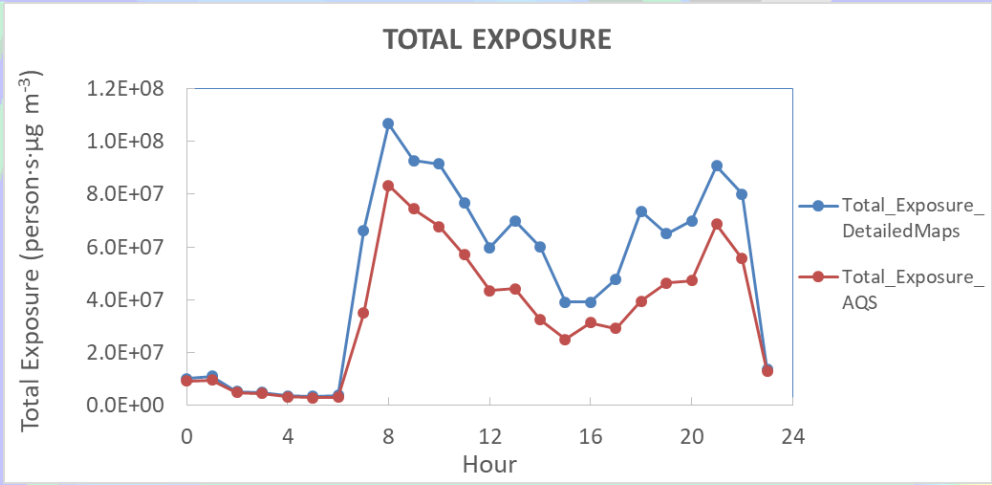
- **Daily Total Exposure** computed using **Concentration Data from Air Quality Monitoring Station** and **Total Number of Pedestrians**

Daily averaged NOx (µg m^{-3})



NOx (AQS) = 74.2 µg m^{-3}

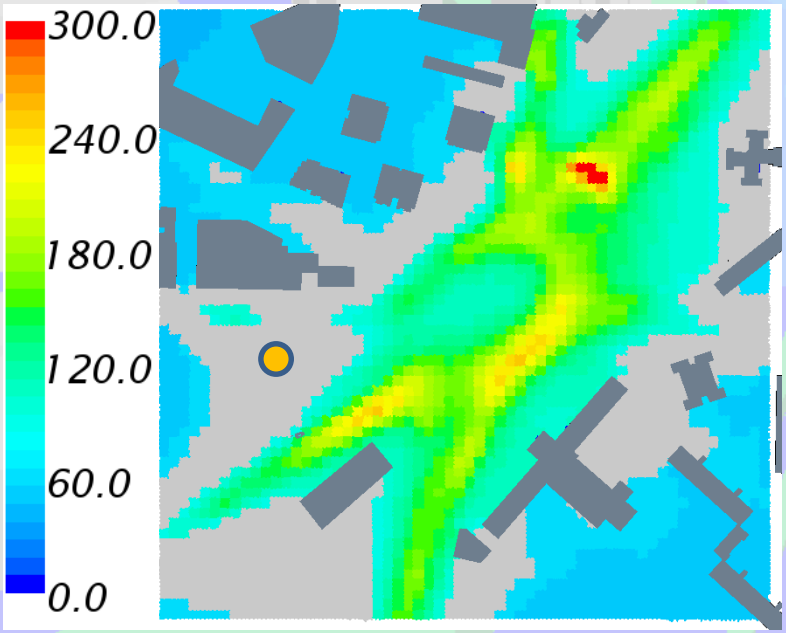
DAILY TOTAL EXPOSURE (person·s µg m^{-3})		Diferences
Detailed Maps	*1.19E+09*	*reference*
$C_{AQS}(day) \cdot TotPed(day)$	0.71E+09	-40.0 %
$\sum_h (C_{AQS}(h) \cdot TotPed(h))$	0.83E+09	-29.8 %



Results: AQMS Spatial Representativeness

- Spatial Representativeness of Air Quality Monitoring Station (AQMS) using concentration similarity criteria.
- Representativeness area (RA) criteria: Concentration = C(AQMS) ± 20%

Daily Averaged NOx ($\mu g\ m^{-3}$)



NOx (AQS) = 74.2 ± 14.8 $\mu g\ m^{-3}$

RA/Atot	A_high/Atot	A_low/Atot
29.8 %	42.7 %	27.5 %

RA: Representativeness area (*grey area in Fig.*)
A_high: Area with higher concentration than station
A_low: Area with lower concentration tan station

Results: AQMS Spatial Representativeness

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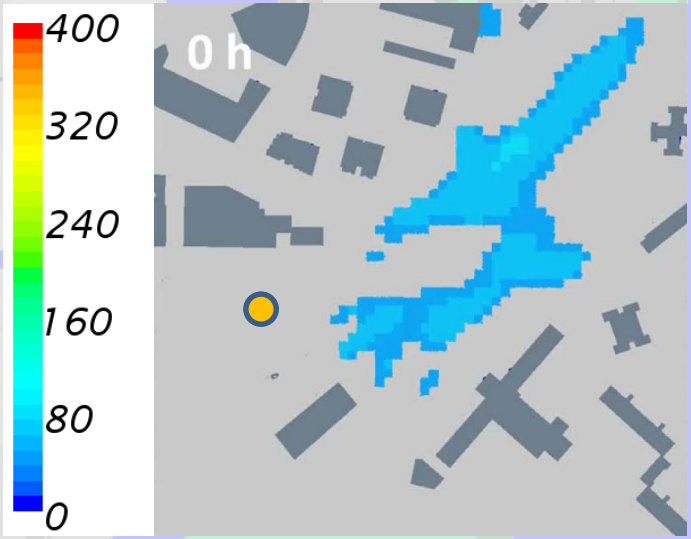
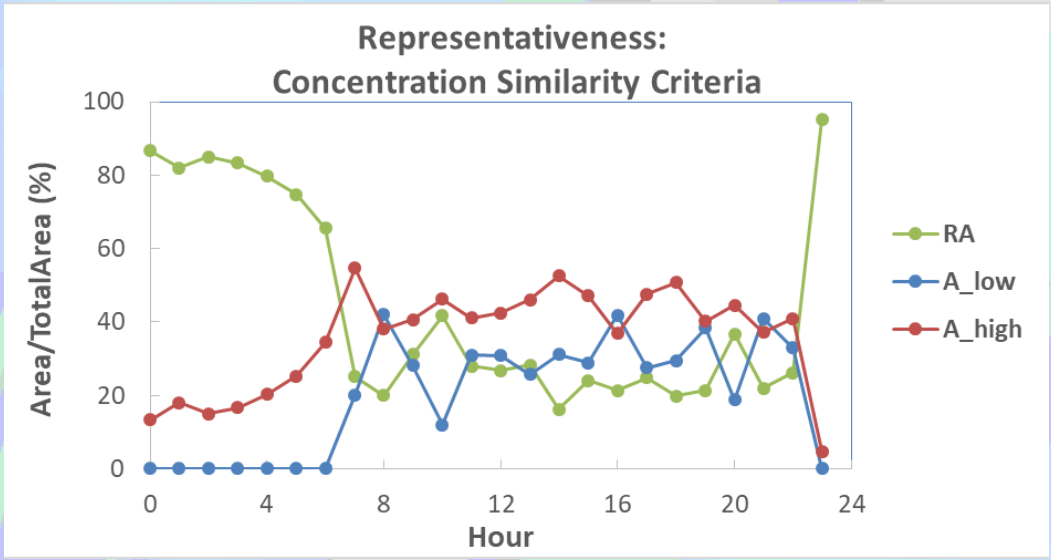
Hourly NOx (µg m^{-3})



Temporal evolution

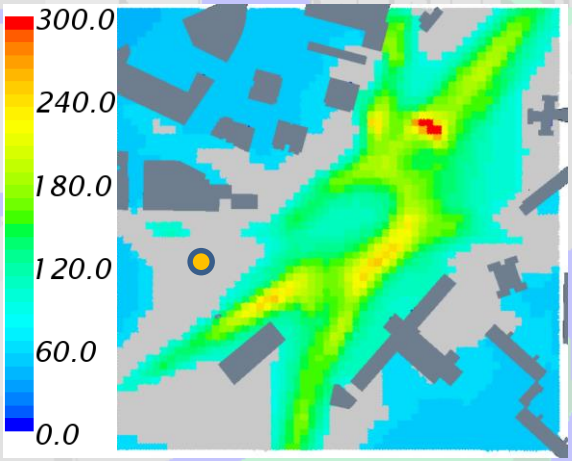


RA: Representativeness area (*grey area in Fig.*)
A_high: Area with higher concentration than station
A_low: Area with lower concentration tan station

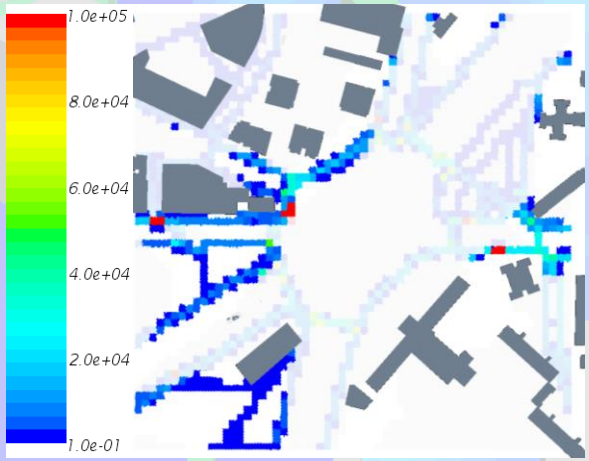
Results: AQMS Spatial Representativeness

- **Spatial Representativeness of Air Quality Monitoring Station (AQMS) using Concentration Similarity + Exposure Criteria.**
- Representativeness area (RA) criteria: Concentration = C(AQMS) ± 20%
- **How many pedestrian are exposured to this concentration?**

Daily Averaged NOx (µg m^{-3})



Daily Total Pedestrians (person·s)



PEDESTRIANS		
P(RA)/Ptot	**P(C_high)/ Ptot**	**P(C_low)/ Ptot**
41.6 %	48.4%	10.0%

AREAS WITH SIMILAR CONCENTRATIONS		
RA/Atot	**A_high /Atot**	**A_low /Atot**
29.8 %	42.7%	27.5%

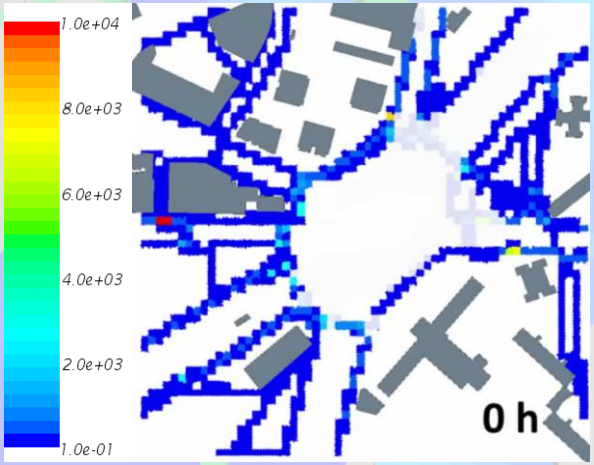
RA: Representativeness area (*grey area in Fig.*)
P(RA): Pedestrians who breathe similar concentration to C(AQS)
P(C_high): Pedestrians who breathe higher concentration than C(AQS)
P(C_low): Pedestrians who breathe lower concentration than C(AQS)

Results: AQMS Spatial Representativeness

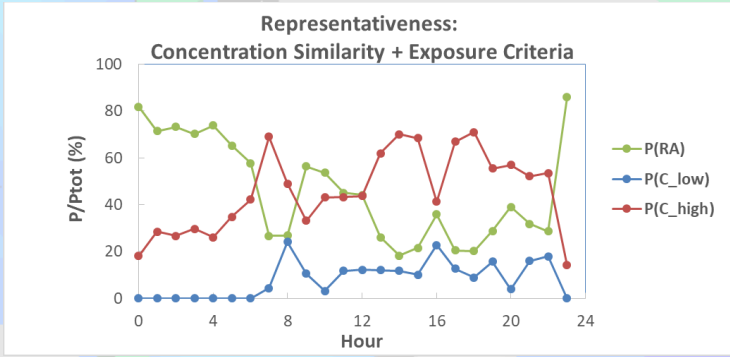
- **Spatial Representativeness of Air Quality Station (AQMS) using Concentration Similarity + Exposure Criteria.**
- Representativeness area (RA) criteria: Concentration = C(AQMS) ± 20%
- **How many pedestrian are exposured to this concentration?**

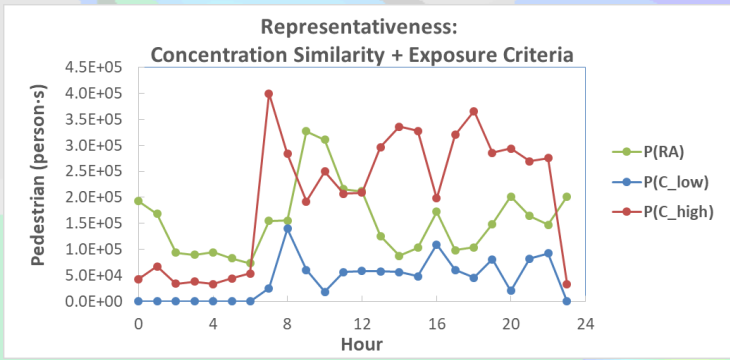
Hourly NOx (µg m^{-3})

Pedestrians (person·s)



Temporal evolution





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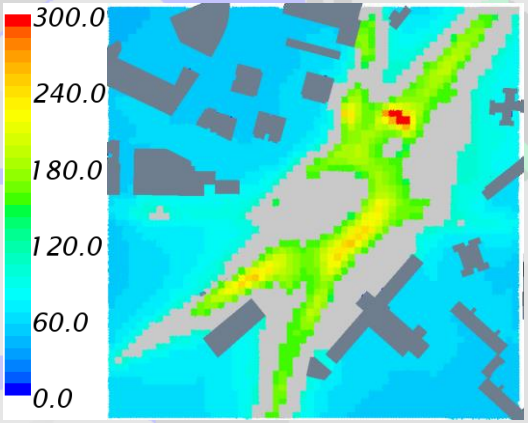
P(RA): Pedestrians who breathe similar concentration to C(AQS)
P(C_high): Pedestrians who breathe higher concentration than C(AQS)
P(C_low): Pedestrians who breathe lower concentration than C(AQS)

Results: AQMS Spatial Representativeness

Where could AQMS be sited to be more representative (exposure)?

- **First approach**: Search a location with a C(AQMS_new) such the computed Daily Total Exposure in the domain equals the Daily Total Exposure computed with high resolution CFD maps

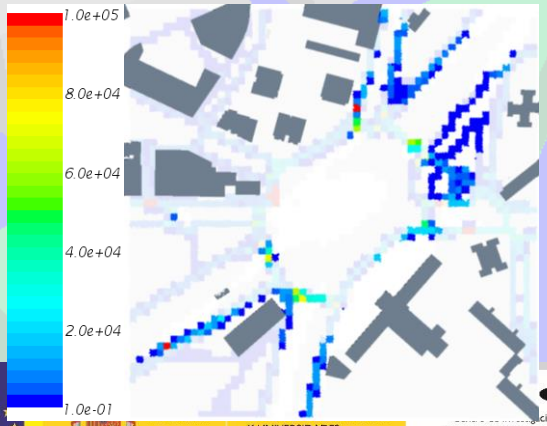
Daily Averaged NOx (µg m^{-3}) **NOx (AQS_new) = 123.6 µg m^{-3}** **NOx (AQS_old) = 74.2 µg m^{-3}**



DAILY TOTAL EXPOSURE (person·s µg m^{-3})		Diferences
Detailed Maps	*1.19E+09*	*reference*
NOx (AQS_new)	1.19E+09	0 %
NOx (AQS_old)	0.71E+09	-40.0 %

AREAS WITH SIMILAR CONCENTRATIONS AQS_NEW			AREAS WITH SIMILAR CONCENTRATIONS AQS_OLD		
RA/Atot	A_high/Atot	A_low/Atot	RA/Atot	A_high/Atot	A_low/Atot
22.0 %	15.2%	62.7%	**29.8 %**	42.7 %	27.5 %

Daily Total Pedestrians (person·s)



AFFECTED PEDESTRIANS - AQS_NEW			AFFECTED PEDESTRIANS - AQS_OLD		
P(RA)/Ptot	P(C_high)/Ptot	P(C_low)/Ptot	P(RA)/Ptot	P(C_high)/Ptot	P(C_low)/Ptot
23.2 %	16.6 %	60.2 %	**41.6 %**	48.4 %	10.0 %

- **Computed Total Daily Exposure can be OK but Representativeness of Air Pollution Breathed is not good.**

Conclusions

- This system of models (CFD + pedestrian microsimulations) can provide pedestrian exposure with high resolution (and a total exposure reference).
- High exposure areas are located mainly in bus stops and crosswalks.
- Detailed exposure maps can help to focus the local strategies to decrease exposure to certain places (e.g. bus stops).
- Computed total exposure using spatial average concentration over the domain and total number of pedestrian is in this case underestimated by 23% and 9% respect reference.
- Computed total exposure using AQMS concentration and total number of pedestrian in this case is underestimated by 40% and 30% respect reference.
- This methodology helps to quantify Spatial Representativeness of AQMS in terms of concentration and exposure. In this case, AQMS is more representative respect to the air pollution breathed by pedestrian (42% of pedestrian) than respect to total area (30 %). More than one factor should be taken into account in this analysis.
- Spatial Representativeness Criteria of AQMS locations is still an Open Question.
- Concentration and pedestrian variability makes difficult to assess population exposure using only one measurement point.

HARMO 19

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Thank you for your attention

Questions?

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